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The Utility of Advanced Distributed Simulation for Command, Control, Communications, Computers, Intelligence, Surveillance and Reconnaissance Systems Testing

by: LTC Patrick M. Cannon, Maj Mark F. Scott,
and Dr. Leslie L. McKee

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Joint Test Force

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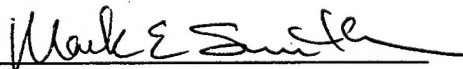
**THE UTILITY OF ADVANCED DISTRIBUTED SIMULATION FOR
COMMAND, CONTROL, COMMUNICATIONS, COMPUTERS,
INTELLIGENCE, SURVEILLANCE,
AND RECONNAISSANCE SYSTEMS TESTING**

5 August 1999

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13. ABSTRACT (Maximum 200 Words) The Joint Advanced Distributed Simulation (JADS) Joint Test and Evaluation was chartered by the Deputy Director, Test, Systems Engineering, and Evaluation (Test and Evaluation), Office of the Under Secretary of Defense (Acquisition and Technology) in October 1994 to investigate the utility of advanced distributed simulation (ADS) technologies for support of development test and evaluation and operational test and evaluation. The End-To-End (ETE) Test evaluated the utility of ADS to support testing of command, control, communications, computers, intelligence, surveillance, and reconnaissance (C4ISR) systems. It conducted its test and evaluation utility evaluation in an ADS-enhanced test environment using the Joint Surveillance Target Attack Radar System (Joint STARS) as one component of a representative C4ISR environment. The ETE Test also evaluated the capability of the JADS Test Control and Analysis Center to control a distributed test of this type and to remotely monitor and analyze test results.				
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FOREWORD

In the early nineties, the proposition that advanced distributed simulation (ADS) was the wave of the future for test and evaluation (T&E) was advanced. Reaction was mixed. At one end of the spectrum were people who believed the need for live testing would fade away, and at the other end were people who scoffed at the notion that ADS had any utility at all for testers. At the policy-making level, expectations were high and skepticism was subdued. At the implementation level, expectations were low and skepticism was high.

The Joint Advanced Distributed Simulation (JADS) Joint Test and Evaluation (JT&E) program was chartered in October 1994 to conduct an objective assessment of the worth of ADS for support of T&E. The joint test force (JTF) conducted tests in three functional areas: precision guided munitions (PGMs); command, control, communication, computers, intelligence, surveillance and reconnaissance (C4ISR), and electronic warfare (EW). While the JTF effort was resource constrained, its results have broad relevance. Each of the test areas is documented in executive-level utility reports. This report addresses the utility of ADS in C4ISR testing.

This report strongly suggest that there is very high utility for ADS in C4ISR testing. This utility arises because 1) C4ISR systems operate in a distributed environment and 2) there is a reasonable match between the technical characteristics of ADS and the technical characteristics of command and control architectures. The functional area of C4ISR relies heavily on information systems technology (IST), and the turnover of that technology is very rapid --- something on the order of every eighteen months. If the Department of Defense (DoD) is to take advantage of advances in IST capabilities new information systems will be continuously evolving requiring the application of new and robust simulation tools for evaluating the suitability and effectiveness of these systems. Use of distributed simulation is particularly well suited for testing in that environment.

This report presents the results of a C4ISR Joint Test that implies the utility of ADS technology as a practical tool that can support early, affordable, and comprehensive, testing of C4ISR systems. It has the potential to enable robust system-of-system testing as well as mission-level and end-to-end evaluations. The intelligent application of ADS technology for testing C4ISR systems can provide these benefits in a cost-effective manner.

We believe that C4ISR program and test managers should familiarize themselves with ADS and routinely consider its use in their deliberations and planning activities. It is our hope that ADS will be treated as a readily available tool. While the use of ADS will not make sense in every case, there are many cases where it not only makes sense, but it may offer the only practical approach to realistic and rigorous C4ISR testing. We will support and assist program and system managers who see applications for ADS in their test events and programs.



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EXECUTIVE SUMMARY

1.0 Overview

The Joint Advanced Distributed Simulation (JADS) Joint Test and Evaluation (JT&E) was chartered by the Office of the Secretary of Defense in October 1994 to investigate the utility of advanced distributed simulation (ADS)¹ technologies for support of test and evaluation (T&E). The JADS program is Air Force led with Army and Navy participation and is scheduled to end in March 2000. This report addresses the second of three separate JADS tests, the End-to-End (ETE) Test, which was completed in March 1999.

The ETE Test evaluated the utility of ADS to support mission-level testing of command, control, communications, computers, intelligence, surveillance, and reconnaissance (C4ISR) systems. The test used the Joint Surveillance Target Attack Radar System (Joint STARS) as one component of a representative C4ISR system. Other C4ISR elements represented in the ETE Test included virtual battlefield entities (including about 10,000 threat entities), manned air and ground operator workstations, an actual Army target analysis cell, a fire direction center, and simulated missiles for attacking selected targets. Tactical communications systems were used between most of these elements. Figure ES-1 shows what a typical C4ISR ADS architecture might look like using a representation of the JADS ETE Test configurations.

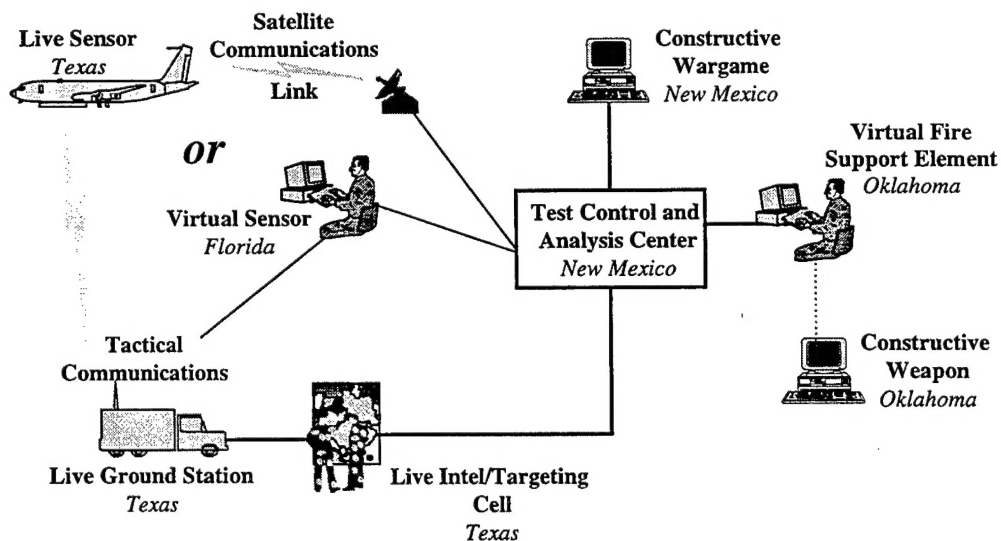


Figure ES-1. Typical C4ISR ADS Architecture.

¹ ADS is a networking method that permits the linking of constructive simulations (digital computer models), virtual simulations (man-in-the-loop or hardware-in-the-loop simulators), and live players located at distributed locations into a single environment/scenario. Such linking can result in a more realistic, safer, and/or more detailed evaluation of the system under test.

There were two separate representations for the Joint STARS E-8C aircraft. In the laboratory configuration, the Virtual Surveillance Target Attack Radar System (VSTARS) radar emulation represented the E-8C radar subsystem and provided the inputs needed to drive target displays on operator workstations. In the live configuration, an actual E-8C aircraft was flown and the workstation operators observed actual live ground targets participating in an exercise along with the virtual battlefield entities.

2.0 End-to-End Test Results and Conclusions

Within the confines of the ETE Test data, our assessment is that the architecture we employed has utility for support of C4ISR T&E, especially realistic mission-level testing. The JADS data indicate that developmental test and evaluation (DT&E) and operational test and evaluation (OT&E) activities incorporating ADS technology are both practical and cost effective.

Key lessons learned:

- Distributed testing often requires linkage among dissimilar facilities, network equipment, and simulations. While practical and cost effective in many cases, implementation is more challenging than many people think. Plan for a number of rehearsals and periods of "fix" time.
- ADS test requirements must be clearly defined early in the test planning phase, since individual facilities are generally unfamiliar with conducting coordinated, distributed T&E tests.
- Instrumentation and data management are a challenge.
- Have a centralized test control center with test controllers who are extremely familiar with the test and network configuration.

Conclusions:

- ADS testing of C4ISR systems is technically feasible, provides valid data, and is cost effective in many cases.
- ADS has great potential as a C4ISR testing tool and provides a viable means of conducting realistic mission-level evaluations.

3.0 Observations for C4ISR T&E

Since all C4ISR systems contain the same basic elements (e.g., sensor(s), sensor platform(s), command and control elements, communication lines, and computer hardware and software), the extension of the ETE Test results to other possible C4ISR applications is relatively straightforward. ADS technology allows the evaluation of human-in-the-loop actions, decision processes, timelines, and interoperability which digital simulations do not model well. Using ADS, a mission-level scenario model can be linked to actual C4ISR hardware and software with tactical operators-in-the-loop and tactical communications links for realistic testing in force-on-force scenarios which cannot be accomplished in live testing.

A test control center is a requirement for all testing, distributed or not. Fortunately, the ETE Test experience suggests that the control center can function from almost anywhere with costs tailored to the test requirements. Thus, a specific test may save resources by using an existing control center.

ADS is not just of value to C4ISR T&E but can be applied throughout the system acquisition life cycle. In fact, the benefits of using ADS are best realized over the life of a program. ADS is an enabling technology for Simulation Based Acquisition (SBA) and the Simulation, Test, and Evaluation Process (STEP) as applied to C4ISR systems, since these systems are naturally distributed by nature. Areas where ADS has relevance:

- ADS can create a cost-effective environment for test preparation to include the development of concepts of operations, refinement of test scenarios, rehearsal of test execution, and data collection and analysis.
- ADS allows the integration of models developed by different acquisition programs.
- ADS can expedite the association of results from live tests with output of simulations.
- ADS supports the execution of the Joint Vision 2010 paradigm, which requires realistic battlespace environments populated with many weapon systems and threats. In particular, ADS allows the large-scale, complex environment evaluations needed for C4ISR systems.
- ADS can support the model-test-model process by providing more realistic test results that can be used to refine digital system models.
- ADS enables the linking and integration of geographically distributed resources from different system representation domains (i.e., digital system model, hardware-in-the-loop laboratory, integrated system test facility, open air range) which can lower testing costs.
- ADS supports experimentation of emerging warfighting concepts and testing new weapon systems.
- ADS can reduce the operations tempo (OPTEMPO) of test participants and evaluators in pretest training and integration periods as well as in the test period itself.

The ETE Test results strongly suggest that ADS has excellent potential for improving C4ISR testing and system acquisition. Thus, test planners and program managers should consider the technology as a relevant tool for their program unless an objective assessment suggests otherwise.

1.0 Purpose and Background

1.1 Report Purpose

This report summarizes the assessment of the utility of advanced distributed simulation² (ADS) for the test and evaluation (T&E) of command, control, communications, computers, intelligence, surveillance, and reconnaissance (C4ISR) systems. This assessment was based on the results and lessons learned from the Joint Advanced Distributed Simulation (JADS) End-to-End (ETE) Test along with results from other related efforts. The benefits of ADS-based T&E and training to C4ISR programs are also summarized.

The assessment presented in this report gives general guidelines for implementation of ADS-based testing of C4ISR systems. Detailed instructions for linking specific C4ISR systems using specific architectures were not developed.

1.2 Joint Advanced Distributed Simulation Program Overview

The JADS Joint Test and Evaluation (JT&E) was chartered by the Deputy Director, Test, Systems Engineering and Evaluation (Test and Evaluation)³, Office of the Under Secretary of Defense (OSD) (Acquisition and Technology) in October 1994 to investigate the utility of ADS technologies for support of developmental test and evaluation (DT&E) and operational test and evaluation (OT&E). The program is Air Force led with Army and Navy participation and is currently scheduled to end in March 2000.

The JADS JT&E charter focuses on three issues: what is the present utility of ADS, including distributed interactive simulation (DIS), for T&E; what are the critical constraints, concerns, and methodologies when using ADS for T&E; and what are the requirements that must be introduced into ADS systems if they are to support a more complete T&E capability in the future.

The JADS JT&E investigated ADS applications in three slices of the T&E spectrum: the System Integration Test (SIT) explored ADS support of air-to-air missile testing; the ETE Test investigated ADS support for C4ISR testing; and the Electronic Warfare (EW) Test examined ADS support for EW testing. The JADS Joint Test Force (JTF) was also chartered to observe or to participate at a modest level in ADS activities sponsored and conducted by other agencies in an effort to broaden conclusions developed in the three dedicated test areas.

² ADS is a networking method that permits the linking of constructive simulations (digital computer models), virtual simulations (man-in-the-loop or hardware-in-the-loop simulators), and live players located at distributed locations into a single environment/scenario. Such linking can result in a more realistic, safer, and/or more detailed evaluation of the system under test.

³ This office is now the Deputy Director, Developmental Test and Evaluation, Strategic and Tactical Systems.

2.0 Supporting Activities and Results

2.1 End-to-End Test

2.1.1 End-to-End Test Overview

The ETE Test evaluated the utility of ADS to support testing of C4ISR systems using the Joint Surveillance Target Attack Radar System (Joint STARS) as one component of a representative C4ISR environment. The intent was to provide a complete, robust set of interactions from sensor to weapon system including the additional intermediate nodes that would be found in a tactical engagement. The test traced a thread of the complete battlefield process from target detection to target assignment and engagement at corps level using ADS.

The ETE Test consisted of four phases. Phase 1 developed or modified the components needed to develop the ADS test environment. Phase 2 used a laboratory environment to evaluate the utility of ADS for DT&E and early OT&E applications. Phase 3 modified the actual Joint STARS equipment and verified its compatibility to interface with the ADS environment. Phase 4 was a live, open air test designed to mix live and virtual targets and provide an end-to-end environment for testing the Joint STARS in its operational environment. ETE testing was completed in March 1999, and results are documented in a separate report for each phase⁴ and in various technical papers (see Appendix D).

2.1.2 End-to-End Test Approach

The test scenario was for a Joint STARS E-8C aircraft to observe a threat rear area of interest and generate target displays on workstations on board the E-8C and at a light ground station module (LGSM) on the ground via the surveillance and control data link (SCDL). The resulting radar reports were provided to a target analysis cell (TAC) for analysis and target assignment. Fire support missions were tasked by the TAC using the Advanced Field Artillery Tactical Data System (AFATDS) to a fire direction center (FDC) and resulted in the launch of an Army Tactical Missile System (ATACMS) missile against selected threat targets.

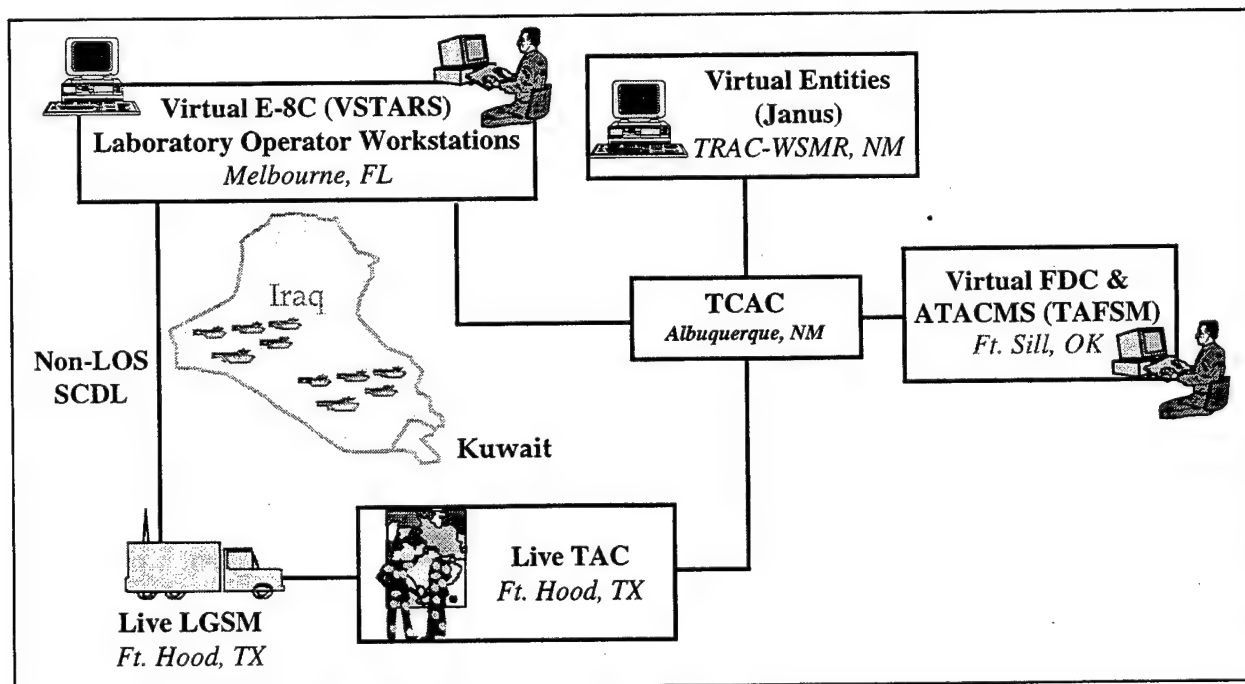
In the ETE Test, the threat ground entities (numbering about 10,000) were generated by the Janus 6.88D simulation at the U.S. Army Training and Doctrine Command Analysis Center (TRAC), White Sands Missile Range (WSMR), New Mexico. An actual manned LGSM and TAC were used at Fort Hood, Texas. The TAC was linked to a FDC at Fort Sill, Oklahoma, by AFATDS terminals at Fort Hood and Fort Sill. The ATACMS missile launch, flyout, and detonation were

⁴ Detailed information on Phases 1, 2, 3, and 4 can be found in their respective reports available at <http://www.jads.abq.com>. (After 1 March 2000 refer requests to Headquarters Air Force Operational Test and Evaluation Center History Office (HQ AFOTEC/HO), 8500 Gibson Blvd. SE, Kirtland Air Force Base, New Mexico 87117-5558 (phone: 505-846-2579) or the Science Applications International Corporation (SAIC) Technical Library, 2001 North Beauregard St. Suite 800, Alexandria, Virginia 22311 (phone: 703-578-8222).)

simulated by the Tactical Army Fire Support Model (TAFSM) simulation hosted at the Depth and Simultaneous Attack Battle Laboratory at Fort Sill. Target engagement results were determined by Janus. The Test Control and Analysis Center (TCAC) in Albuquerque, New Mexico, provided test control, monitored the health of the network, and ensured that adequate data flowed in support of the test. All players were linked by means of a T-1 wide area network (WAN) or by tactical communications links.

There were two separate representations for the E-8C aircraft.

- In the laboratory configuration tested in Phase 2 (Fig. 1), the Virtual Surveillance Target Attack Radar System (VSTARS) emulation represented the E-8C radar subsystem and provided the inputs needed to drive target displays on Advanced Technology Work Stations (ATWS) (representing displays on board the E-8C aircraft) and the LGSM. VSTARS was operated at the Northrop Grumman Surveillance and Battle Management Systems facility in Melbourne, Florida. SCDL traffic was transmitted over a separate, dedicated T-1 link between Melbourne and Fort Hood.
- In the live configuration tested in Phase 4 (Fig. 2), an actual E-8C aircraft was flown over Fort Hood and observed live targets participating in an exercise. Entity state data for the virtual entities simulated by Janus were uplinked to the aircraft via a satellite communications (SATCOM) link (the uplink feed was from the Northrop Grumman facility in Melbourne, Florida), and simulated radar returns for the virtual entities were inserted into the radar stream. The radar signals for both the live and the virtual targets were processed together on board the aircraft resulting in nearly seamless displays on the ATWS.



LOS = line-of-sight

Figure 1. ETE Test Laboratory Configuration

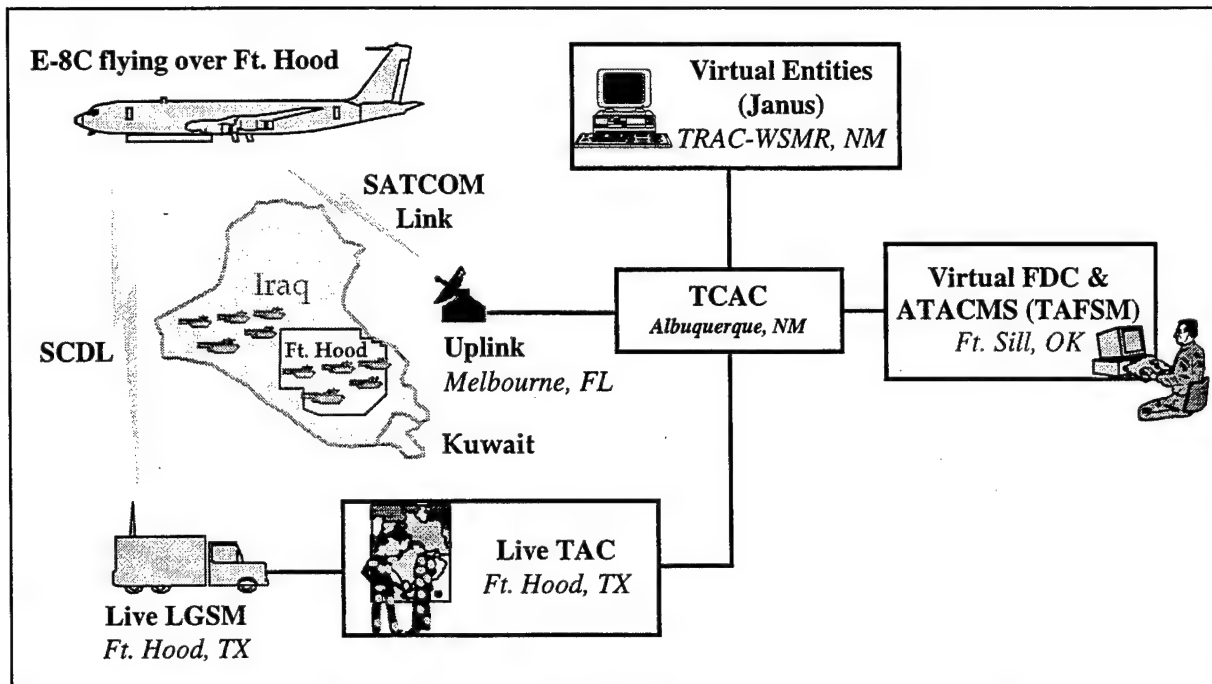


Figure 2. ETE Test Live Configuration

Entity state and ATACMS fire and detonate messages were transmitted among the players using DIS protocol data units. However, the C4ISR-related communications employed tactical protocols and doctrinally correct means:

- Tactical SCDL messages were used.
- The LGSM communicated with the TAC using the Common Ground Station-100 (CGS-100), a subsystem of the Compartmented All Source Analysis System (ASAS) Message Processing System (CAMPS).
- The TAC communicated with the FDC using tactical AFATDS messages.

2.1.3 End-to-End Test Results

The key results from ETE testing (see ETE Test reports for details):

- Both ADS configurations generated valid Joint STARS data, as judged by subject matter experts.
 - It was specifically validated that Janus 6.88D represented vehicle behavior to the degree detectable by the Joint STARS, as judged by Joint STARS operators viewing vehicle movement presented by the Joint STARS operator workstation.
 - Test participants could not identify any Joint STARS radar simulation process or function that limited their ability to perform their mission/job or altered their approach to their mission/job.
 - The credibility of the Joint STARS data was enhanced by the use of actual operational hardware (e.g., ATWS, LGSM, AFATDS) with trained operators whenever possible.

- Sufficient data were collected to support evaluation of most of the Joint STARS multiservice operational test and evaluation measures. These measures were not evaluated by JADS analysts since the JADS objective was to evaluate ADS-based testing not Joint STARS.
- When live and virtual entities were mixed using the live ETE Test configuration, it was impossible to distinguish between them based upon size, color, contrast, and movement. However, the live and virtual areas could be distinguished based on the different scenarios used and civilian traffic “clutter.” The live area contained civilian traffic around Fort Hood, and the virtual area contained simulated battlefield entities in Iraq. If the live entities had simulated a battle in Iraq, the live and virtual entities would have been indistinguishable.
- The ETE Test required only a small fraction of the T-1 bandwidth (1.544 megabits per second). This indicates that a much higher data transfer rate (e.g., more nodes or entities) could be applied to ADS testing without causing bandwidth problems.
- The live testing using the SATCOM link to the E-8C aircraft showed that all the available SATCOM link bandwidth was required for data transmission, and that buffering was needed at times to handle periods of heavy scenario activity. Without buffering, the SATCOM link exhibited an average latency of around two seconds. With buffering, the latency approached six seconds.
- The ETE Test exhibited acceptable latency values. In other words, the latencies experienced during testing did not affect the validity of test results.
- The ETE Test network was highly reliable during testing, largely because of the ETE Test team’s extensive pretest risk reduction efforts.
- Test control procedures were refined throughout the preparation process and worked well during testing.

2.1.4 End-to-End Test Lessons Learned

The key technical lessons learned:

- Simulations, when used in ADS testing, should be carefully planned and developed. Using reliable simulations is important for a successful test.
- Distributed testing often requires linkage among dissimilar facilities, network equipment, and simulations. However, careful planning can significantly reduce the potential for difficulties arising from network interface problems.
- Time sources must be synchronized using a “master clock” and then validated at each network node.
- Special test equipment and networking tools are necessary for distributed testing. The tool set must be able to rapidly isolate the specific cause of network and ADS/DIS problems.

The key infrastructure and process lessons learned:

- ADS test requirements must be clearly defined early in the test planning phase, since individual facilities are generally unfamiliar with conducting coordinated, distributed tests.
- Develop contingency plans that allow quick decisions on alternatives and prevent unexpected equipment and communications problems from completely disrupting the test.

- Use a stepped approach to testing where each successive ADS test builds on the success of earlier tests. This “test, analyze, fix, test” approach, in concert with structured, independent testing of the network, will greatly improve the chances for successful ADS testing.
- Risk reduction testing prior to actual test execution provided effective rehearsals and was helpful for troubleshooting.
- Detailed planning for data management is necessary before testing commences.
- Have a centralized test control center with test controllers who are extremely familiar with the test and network configuration.
- Personnel involved in a distributed test need to understand the “big picture.” When people are geographically separated, it becomes easy for them to focus on their own individual portion of the test. When problems arise, personnel who understand the entire test and the overall network will find solutions much faster.

2.1.5 End-to-End Test Conclusions

The ETE Test live ADS configuration has utility for realistic OT&E to include mission-level testing of C4ISR systems.

- In contrast to ADS-supported testing, most traditional live C4ISR testing cannot be done at the mission level because of the unavailability and prohibitive cost of involving the required numbers of live battlefield entities and limited access to key real world systems because of their limited numbers and high usage.
- The use of ADS permits the number of targets to be greatly augmented by the seamless integration of live and virtual threat entities while operating the sensor/sensor platform in the actual operational environment.
- Realism and the credibility of test results are enhanced by the use of actual operational hardware by trained operators and by the employment of the sensor in a real open-air environment subjecting it to actual background and clutter effects.

The ETE Test laboratory ADS configuration has utility for:

- C4ISR DT&E, since laboratory/brass board system under test configurations can be used, and multiple repetitions of the same scenario can be performed for parametric testing.
- Realistic rehearsal and refinement of live test scenarios, since multiple repetitions of the scenarios can be performed using the same equipment operators as the live test.
- Early operational assessment of C4ISR system components prior to building them by using laboratory/brass board configurations for the new components (e.g., sensor/sensor platforms) linked to existing tactical hardware manned with actual operators for the other components (e.g., command and control [C2] elements).⁵

Both ADS configurations have utility for C4ISR system training.

- Conventional training can be limited by the availability of those assets making up the C4ISR system’s operational environment. ADS technology, by simulating those key assets, can provide longer periods of time for realistic operation of the C4ISR system.

⁵ The assumption here is that only one component/element of an existing C4ISR system is being upgraded, and the other elements are to be unchanged.

- C4ISR system operators can take advantage of the additional training time provided by ADS technology to confirm current tactics and to test “what if” scenarios and new tactics.
- ADS simulations can help C4ISR system operators familiarize themselves with the maneuver tactics of foreign armed forces – valuable experience for possible future deployments.

2.2 Supporting Studies Summary

In addition to the ETE Test results, other studies were performed both inside and outside of the JADS JTF. The findings of those studies relevant to C4ISR ADS applications are summarized as follows:

- DIS-compatible interfaces are being developed that will permit combat scenario simulations to provide the battle stimuli for the operational testing of C4I systems [Ref. 1].
- DIS-based programs have been proposed for testing command, control, and communications (C3) [Ref. 2], modeling airborne reconnaissance systems [Ref. 3], prototyping twenty-first century command and control environments [Ref. 4], simulating C2 [Ref. 5], C3 [Ref. 6], and command, control, communications and intelligence (C3I) environments [Ref. 7].
- Distributed Theater Missile Defense (TMD) testing is being performed using the Theater Missile Defense System Exerciser (TMDSE) at the Joint National Test Facility (JNTF). Using DIS protocol data units (PDUs), TMDSE injects a real-time, common threat scenario into real, geographically distributed tactical sensors and weapon systems. The tactical systems respond in real time via their respective tactical communication data nets allowing each individual TMD system to operate synergistically in a tactically realistic battlefield. TMDSE provides a real-time, hardware-in-the-loop, software-in-the-loop, tactical communications-in-the-loop, tactical operator-in-the-loop, geographically distributed interactive test capability [Ref 8].
- The Joint Theater Missile Defense (JTMD) Attack Operations (AO) JT&E used a large-scale, man-in-the-loop distributed simulation architecture to investigate the capability of a commander in chief to integrate near-term reconnaissance and surveillance sensors, C4I assets, and attack systems in order to conduct TMD attack operations in several theaters of operations with varying force structures [Refs. 9, 10].
- The Simulation Interoperability Standards Organization (SISO) Implementation Study Group for C4I-to-Simulation Interfaces (ISG-C4I) has been formed to aid in the standardization of the interfacing between real C4I and simulations [Ref. 11].
- The growing importance of the high level architecture (HLA) is reflected in discussions on the implementation of a prototype C4I federation object model [Ref. 12] and the development of a C4ISR analysis federation [Ref. 13].

- The use of HLA⁶ overcomes many limitations and undesirable features of DIS standards by allowing data protocol flexibility, eliminating unnecessary coordinate transforms, and reducing the amount of data transmitted between nodes by only transmitting entity attributes that have changed [Ref. 14]. HLA implementation for C4ISR scenarios has already been demonstrated in several programs.
 - The Synthetic Theater of War (STOW) team has demonstrated its entity-level simulation in the first large-scale, (3,700 platforms and 8,000 objects) HLA-compliant exercise utilizing the runtime infrastructure (RTI) [Ref. 15]. The STOW exercise included a Joint STARS federate [Ref. 16].
 - The Simulation, Testing, Operations, Rehearsal Model (STORM) is being developed as an HLA-compliant distributed testing tool for the Army's Force XXI Battle Command Brigade and Below (FBCB2) [Ref. 17]. STORM will permit transmission of simulation information to and from live forces allowing for a relatively "seamless" synthetic battlefield environment.
 - The Joint Simulation System (JSIMS) program is developing HLA-compliant interfaces among simulations and operational C4I systems [Ref. 18].
- Project Constellation is a Test and Evaluation Command (TECOM) Virtual Proving Ground (VPG) initiative to integrate testing and simulation/stimulation tools for distributed testing of systems. Project Constellation has used distributed sensor-to-shooter test beds with C4ISR elements to identify and solve distributed testing issues, especially those related to controlling the distributed environment [Ref. 19].
- The Foundation Initiative 2010 (FI 2010) project, sponsored by the Central Test and Evaluation Investment Program (CTEIP), is designed to provide test capabilities to upgrade the aging Department of Defense (DoD) ranges, facilities, and simulations [Ref. 20]. FI 2010 products will provide cost-effective interoperability among test resources, across phases of the acquisition process, and between test resources and C4ISR resources. These products will support linked tests and exercises that integrate resources from the live, virtual, and constructive domains across all mission areas, services, and all test resource categories.
- The FI 2010 project will also provide a common range architecture called the Test and Training Enabling Network Architecture (TENA) to support (a) test and training range operations, (b) development of range instrumentation, (c) easy assembly and configuration of test resources, (d) execution of test events, and (e) analysis and reporting of test event results [Ref. 20].

⁶ HLA has been mandated by the Department of Defense (DoD) for linking distributed simulations [Ref. 24]. HLA uses a standard set of rules, tools, and a runtime infrastructure (RTI) to allow simulations to send and receive information. HLA allows the simulations to treat communications in a more abstract manner by providing a common interface specification and isolating the simulations from communications protocol implementations. Because simulations can be less aware of each other, HLA should encourage reuse of existing models for different applications. There are also no standard data formats analogous to DIS PDUs. Users can form their own messages based on their needs. Likewise, users can use PDUs if they feel that the PDUs represent the data necessary for their simulation. In most cases, the conclusions from DIS-based testing should directly apply to HLA-based distributed testing.

3.0 Overall Advanced Distributed Simulation Utility Assessment

3.1 JADS Issues

The JADS JT&E program was chartered to investigate the utility of ADS for both DT&E and OT&E. The charter letter identifies three issues to be addressed [Ref. 21].

- Investigate the present utility of ADS, including DIS, for T&E. The utility assessment includes evaluating the validity of data from tests using ADS and the benefits of using ADS in T&E.
- Identify the critical constraints, concerns, and methodologies when using ADS for T&E.
- Identify the requirements that must be introduced into ADS systems if they are to support a more complete T&E capability in the future.

The ability of ADS to support C4ISR T&E will be assessed in terms of these issues.

3.2 General Utility of ADS for T&E of C4ISR Systems

The assessments in this section represent extrapolations of the results of JADS testing and related ADS programs and are based on JADS experience and insight from executing the JT&E without rigorous analysis or supporting data. Rationales for the assessments are given, as appropriate.

3.2.1 General Utility Assessment

ADS has utility for C4ISR DT&E and OT&E.

- As demonstrated by the success of the JADS ETE Test, ADS-supported tests can provide valid mission-level C4ISR performance evaluations in a number of areas addressed by both DT&E and OT&E.
- ADS-supported tests can mitigate or eliminate traditional T&E shortfalls especially for force-on-force, system-of-systems scenarios and permit following the thread of a complete battlefield process (e.g., sensor-to-shooter applications). In fact, ADS-supported tests may be the only way to generate the data needed to calculate some effectiveness and performance measures. Traditional C4ISR testing-related shortfalls that ADS can overcome include [Ref. 22]:
 - human interaction not represented,
 - nonrepresentative force levels,
 - inadequate quantity and types of threat systems, targets, and friendly systems,
 - insufficient test articles,
 - unrealistic test scenarios, and
 - insufficient number of test events.
- The JADS JTF has judged ADS to have significant utility in all mission areas evaluated (C4ISR, precision guided munitions, and EW). However, the strongest utility was found to be for testing C4ISR systems or those systems that interact with C4ISR systems.

- There are significant benefits in using ADS for C4ISR T&E (see Section 3.2.2).

3.2.2 General ADS Benefits

The benefits of ADS-supported testing are best realized when this testing approach is added to a total C4ISR testing program. ADS-supported tests are not meant to replace any of the current testing techniques (e.g., analytical studies, laboratory/field tests, hardware-in-the-loop tests, installed system test facility tests, live tests), but rather to supplement current techniques and provide a more comprehensive evaluation of a C4ISR system. When the appropriate mix of testing techniques is used, benefits are realized from the addition of ADS-supported testing.

The primary benefits of ADS-supported C4ISR testing:

- Distributed test linking techniques permit realistic system-of-systems, mission-level evaluations to be performed at affordable costs. The realism results from the combination of
 - large numbers of virtual battlefield entities augmenting a limited number of live entities,
 - large virtual battlespace with an operationally realistic scenario driver and accredited scenario,
 - human operators and decision-makers-in-the-loop using actual workstations,
 - communicating by the use of tactical message protocols, and
 - real sensors and sensor platforms operating in the actual environment.
- An ADS-supported test allows the evaluation of the value of a C4ISR system to the overall mission accomplishment. The same scenario can be replayed with and without the C4ISR system to determine the impact of the system on the outcome of the battle.

Other benefits include the following.

- ADS provides an efficient method for C4ISR interoperability testing. Instead of having to take a particular system to separate test facilities for each element with which it must interoperate in a sequential fashion, all facilities/elements can be linked together for concurrent testing, saving time and money. Concurrent linked testing also simplifies the analysis and correlation of test results since a common scenario and testing environment is achieved.
- The use of ADS in support of testing provides greater scalability and flexibility than live testing. The number of simulated entities can be readily scaled for a particular scenario by the use of a digital model. Also, the type of representation for a given player (i.e., live, virtual, or constructive) can be changed based on considerations of cost, schedule, fidelity, operational availability, etc.
- Dedicated ADS-supported tests have advantages over piggybacking on training exercises.
 - Scheduling conflicts with the training exercise are eliminated.
 - Dedicated ADS-supported tests are more controllable, since there is no conflict over testing and training objectives and since virtual entities can be precisely controlled.
 - Virtual entities do not need instrumentation and are not subject to instrumentation errors.
- ADS-supported tests can be repeated with the same scenario and synthetic environment each time for greater confidence in results.

- ADS-supported tests can be used to verify software and techniques for sensor fusion. Multiple sensor representations can be linked with a common scenario/synthetic environment and sensor outputs can be fed into the actual fusion software/techniques.
- The use of simulations for sensor platforms and battlefield entities means that any conceivable test case or scenario can be run without safety or asset availability concerns.
- Live tests can be realistically rehearsed using ADS (since the actual scenarios and equipment operators can be used), resulting in more productive live testing.
- The same ADS configuration can be used for DT and OT testing, as well as realistic training. Only the type and quantity of instrumentation need to be changed as required by the DT, OT or training objectives.
- ADS can reduce the operations tempo OPTEMPO of test participants and evaluators during pretest training and integration as well as during the test itself. Distributed testing allows personnel to participate from their home locations eliminating travel time, and realistic training and rehearsal periods result in more efficient test preparations.

3.2.3 General Role of ADS in C4ISR System Acquisition Life Cycle

The Department of Defense is seeking to streamline the acquisition process by the use of simulation technology through a strategy called Simulation Based Acquisition (SBA). The goals of SBA are to [Ref. 23]

- substantially reduce the time, resources, and risk associated with the entire acquisition process,
- increase the quality, military worth, and supportability of fielded systems while reducing total ownership costs throughout the total life cycle, and
- enable integrated product and process development across the entire acquisition life cycle.

A key element of SBA is the Simulation, Test, and Evaluate Process (STEP), which is defined as “an iterative process that integrates simulation and test for the purpose of interactively evaluating and improving the design, performance, joint military worth, survivability, suitability, and effectiveness of systems to be acquired and improving how those systems are used [Ref. 24].”

Under the SBA and STEP concepts, the cost of testing is reduced because investments in simulations in early acquisition phases can be leveraged rather than duplicated in later stages. Reliability is increased because of the iterative approach inherent to SBA and STEP where results from field tests are incorporated back into models in a “model-test-model” paradigm. Overall cost of acquisition is reduced because system evaluators can merge information from multiple acquisition phases maximizing insight to system performance.

ADS is particularly useful in supporting SBA and STEP as applied to C4ISR systems, since these systems are distributed by nature. Areas where ADS has relevance⁷:

- ADS can provide a framework for the integration of models developed by different acquisition programs, since the use of ADS techniques (e.g., linking via network interfaces

⁷ As in Sections 3.2.1 and 3.2.2, the assessments in this section are extrapolations of the results of JADS testing and related ADS programs and are based on JADS experience and insight.

and data protocols) can permit disparate simulations to be linked, as demonstrated during JADS testing.

- ADS can expedite the association of results from live tests of a C4ISR element with the output of simulations of the element. Using the same approach as the ETE Test, the element can either be represented by the actual hardware or by a simulation and is linked in either case to the same representations of the other elements of the C4ISR system. Since the same scenarios and synthetic environment can be used, correlation of results between the live element test and the element simulation is relatively straightforward and can support the model-test-model process at the element level.
- ADS can also support the model-test-model process at the system-of-systems level by providing more realistic mission-level test results that can be used to refine digital system models for the entire C4ISR system.
- ADS supports the execution of the Joint Vision 2010 paradigm which requires realistic battlespace environments populated with many weapon systems and threats. In particular, ADS allows the large-scale, complex environment evaluations needed for C4ISR systems.
- ADS enables the linking and integration of geographically distributed resources from different system representation domains (i.e., digital system model (DSM), hardware-in-the-loop lab, integrated system test facility, battle labs, open air range) which can lower test costs.
- ADS supports experimentation of emerging warfighting concepts and testing new weapon systems.

Further, ADS techniques can be applied to all C4ISR element acquisition phases.

- Concept Exploration. If a C4ISR element DSM becomes available during this initial system acquisition phase, ADS linking techniques can be used to provide a more realistic battlefield environment and to permit human interactions with the simulated element. This capability is especially useful for development of a concept of operation (ConOps) for the emerging element system.
- Program Definition and Risk Reduction. As prototype C4ISR element system hardware is developed, ADS-based testing can be expanded and refined. ADS configurations can be used to support early operational assessments and for more realistic specification compliance testing during DT&E.
- Engineering and Manufacturing Development. Mission-level evaluations have replaced traditional requirements-based OT&E to determine whether the system supports the warfighter [Ref. 25], and ADS-based testing is well suited for this application. By using ADS, the C4ISR system can be placed in a realistic operational environment and valid data can be collected for the evaluation of operational measures.
- Production, Fielding/Deployment and Operational Support. By permitting operator-in-the-loop operations with tactical hardware, ADS can support the development of tactics and operational procedures in conjunction with realistic training. ADS can also be used for the development of integrated logistics concepts.

ADS is also useful for supporting the iterative spiral development process. As the C4ISR element undergoes improvements and upgrades, ADS can be used to more realistically to

- verify the element system's design,
- confirm that design risks have been controlled,

- certify readiness for operational testing, and
- evaluate the system's operational effectiveness, suitability, and survivability.

3.3 Critical Constraints, Concerns, and Methodologies for C4ISR T&E

Constraints with respect to the application of ADS technology can be summarized as follows.

- There are limited tools (e.g., network design software, network test and analysis hardware/software, distributed test control hardware/software), expertise, and resources for implementing ADS-based testing.
- There are fundamental ADS-related constraints.
 - Latency is not normally a limitation for C4ISR applications.
 - Bandwidth can limit the number of entities represented in a scenario or their update rate. However, this was not an issue for the ETE Test involving about 10,000 entities.
 - Bandwidth limitations can also make it difficult to pass detailed environmental data among players. The standard practice is to employ a common environmental database at each node to ensure that all simulated sensors see the same virtual environment.
 - Special interfaces are needed to inject virtual entities into live systems. Such interfaces may be used to inject virtual entities behind a live sensor but before sensor signal processing, as was done in the ETE Test.

There are concerns which must be addressed for the proper implementation of ADS. These include the following:

- ADS implementation adds another layer requiring management oversight. This is minimized by integrating the ADS implementers into the test force, as demonstrated during the JADS JT&E.
- ADS implementation requires additional infrastructure in a test, and currently there is little or no existing infrastructure. However, there are DoD-sponsored options for the WAN portion of the infrastructure including the Defense Research and Engineering Network (DREN), Defense Simulation Internet (DSI), and Secure Internet Protocol Router Network (SIPRNET).
- The integration of various data collected at distributed sites into a centralized data set can be difficult. However, proper planning can greatly mitigate this. In fact, the WAN can be used post-test to transmit data collected at the distributed sites to a central analysis facility, as done during JADS testing.
- Potential implementers don't know where to go to get information and help on implementing ADS, e.g., available simulations, facilities, and tools. This concern is addressed in appendices to this report.
 - Appendix C - checklist for implementing ADS-based tests
 - Appendix D - bibliography of all JADS ETE-related reports and papers
 - Appendix E - list of ADS-related Web sites
- The cost of implementing ADS is a common concern. There can be significant up-front costs, since most existing facilities were not designed to be linked and will thus require some modification along with the appropriate interfaces before linking is possible. However, this cost can be amortized over all phases of a C4ISR development and testing program and even

across related C4ISR programs. Also, it should be noted that the cost per byte of data is generally less than for a live test, since a distributed test can generate considerably more data than a live test.

- Distributed people and resources require effective communications and frequent coordination, but this can be done with the right organization and lines of communications.
- Security can be a concern when linking facilities with different security requirements. Although special attention must be given to developing and coordinating security procedures, the process is straightforward. For example, the ETE Test linked classified and unclassified facilities.
- Concerns over the availability of specific ranges and facilities can be alleviated by identifying substitute resources.
- Effective centralized control of distributed tests can be challenging, but it can be done with proper planning and tailored investment.

A number of methodologies apply for ADS implementation. These methodologies are being separately developed by the JADS JTF and include:

- *JADS Special Report on ADS T&E Methodologies* including:
 - *ADS Test Concept Development Methodology*
 - *ADS Test Planning and Implementation Methodology*. This is outlined in Appendix C, ADS Test Implementation Checklist, and illustrates the strong system engineering approach needed to solve problems.
- *JADS Special Report on ADS Cost Guidance* including overall potential benefits and cost savings associated with the use of ADS
- *JADS Special Report on Verification, Validation, and Accreditation of Distributed Tests*
- *JADS Special Report on Networking and Engineering*
- *JADS Special Report on Distributed Test Control*
- *JADS Special Report on Programmatic Challenges to ADS-Based T&E*

4.0 ADS-Supported C4ISR Testing Applications

This section considers other applications of ADS to C4ISR testing beyond that of the ETE Test. C4ISR systems are distributed by their nature and obvious candidates for distributed testing. Since all C4ISR systems contain the same basic elements (e.g., sensor(s), sensor platform(s), command and control elements, communication lines, and computer hardware and software), the extension of the ETE Test results to other possible C4ISR applications is relatively straightforward.

4.1 Common Considerations for Element Representation

Human-in-the-Loop. A key element in C4ISR testing is the evaluation of human-in-the-loop actions, decision processes, and timelines, which digital simulations do not model well. For this reason, ADS-supported C4ISR testing should include live participants for all key operators and decision makers. If available, the actual equipment/tactical workstations/command posts should be employed and manned by trained personnel. If actual equipment is not used, the human-machine interface can be represented by computer displays that present the same information in the same format.

Communications Links. When the actual workstations are used in C4ISR testing, the actual tactical communication links and message protocols may be used. However, geographical separation between C4ISR system elements may prevent line-of-sight communications. In this case, land lines (i.e., T-1 links) may have to be used, but the messages could still use realistic tactical protocols and communication equipment. For example, the ETE Test used land lines but employed such doctrinally correct communications as the CGS-100 with remote workstations, SCDL messages between the ATWS and the LGSM, and AFATDS-to-AFATDS message traffic.

Sensor and Sensor Platform. There are different considerations depending on whether the sensor and sensor platform representations are live or simulated.

- Live Sensor/Platform. Use of the actual sensor and sensor platform will provide real background, clutter, and contrast scenes for target detection. However, the full battlefield array of potential targets generally cannot be provided from live entities. Thus, the live targets must be supplemented with virtual entities using interface hardware and software which can integrate live and virtual targets.
- The preferred location of the interface is behind the sensor and before any sensor signal processing so that live and virtual targets are detected and processed in the same manner. This was the approach used in the ETE Test; virtual targets were uplinked to the aircraft and injected into the Joint STARS radar scene before processing and display to the E-8C ATWS operators.
- In some applications, it may be impossible or unnecessary to locate the interface on the sensor platform. For example, with an unmanned aerial vehicle (UAV) sensor, weight and space limitations may prevent installation of the interface hardware on the UAV.

However, the UAV video is not observed on the platform but at a ground station. Thus, the interface could be located at the UAV ground station.

- **Simulated Sensor/Platform.** If the sensor and sensor platform are represented by simulations, then the scenario will also be provided by simulations, and the interface will be relatively straightforward. The actual sensor signal processors and software can still be used to prepare the sensor output for the actual operator displays, thus providing realistic testing of these subsystems.

Battlefield Scenario. The major shortfall in current C4ISR developmental and operational testing is in providing realistic battlefield scenario stimuli to the sensor subsystem. By using accredited combat simulations, an ADS-enhanced synthetic environment can allow for testing that would otherwise be impractical. A number of accredited simulations exist for representing the battlefield scenario, and the choice of simulation depends on

- number of virtual entities needed,
- level of control needed over the simulation,
- need to interface at the entity or the aggregate level,
- need to represent a battalion-, brigade- or corps-level scenario,
- size of the terrain box required for the C4ISR test,
- extent of the simulation's verification and validation "pedigree," and
- compatibility of the simulation with the other components of the ADS synthetic environment.

Weapon System. Although not all C4ISR tests include a shooter, mission-level evaluations of many C4ISR systems require evaluating the combat effectiveness impacts of the system in locating and identifying enemy targets which are subsequently destroyed. Hence, the weapon system must also be represented in mission-level evaluations. Since most of the targets in the ADS-supported test are simulated, the weapon itself will normally also be simulated, although with tailored fidelity according to test requirements.

4.2 Specific Example - National Missile Defense

As an example, the application of ADS to C4ISR system testing involving National Missile Defense (NMD) scenarios is considered. Because of the large number of variables, safety concerns, and the high costs associated with live testing, the NMD program must rely heavily on modeling and simulation during T&E. Since the NMD systems will be operationally distributed with many operators and decision makers, ADS-supported testing would provide much of the desired operational realism.

As summarized in Section 2.2, distributed testing is already being used to support the TMD program. Under the sponsorship of the Ballistic Missile Defense Organization (BMDO), the TMDSE at the JNTF uses DIS PDUs to support real-time, operator-in-the-loop testing of real, geographically distributed TMD tactical sensors and weapon systems that are linked using their respective tactical communication data nets [Ref. 8]. Using TMDSE as a scenario driver, the feasibility of distributed testing of TMD family-of-systems (FoS) architectures has already been demonstrated. The application to NMD architectures would seem to be straightforward.

The NMD program has used the Integrated System Test Capability (ISTC) to support system-level processor-in-the-loop tests. In the current implementation, individual computer stations or nodes within the Advanced Research Center (ARC), Huntsville, Alabama, will represent the various elements of the NMD architecture (e.g., Battle Management Command, Control, and Communications (BM/C3), Upgraded Early Warning Radar (UEWR), ground based radar (GBR), Space Based Infrared System (SBIRS), ground based interceptor (GBI)). These nodes are linked together, and ISTC supplies them with the test scenario (simulated threats including threat signatures and kinematics and environments). These tests use the actual element mission and communications processors and software, if available (otherwise the element is represented by a digital model), but there are no human-in-the-loop interactions [Ref. 26].

There is a proposal to use ISTC as part of distributed NMD testing by incorporating ISTC into system integrated exercises (SIEs) [Ref. 26]. SIEs are system-level distributed tests, and ISTC would be used as the test scenario driver. The NMD element representations and drivers for the SIEs will evolve over time from digital models to actual hardware and software with real operators. In particular, the SIEs would be used to evaluate the NMD BM/C3 capability for the designated operational commander to plan, coordinate, direct, and control NMD weapons and sensors, a critical issue in the NMD program.

Distributed tests involving the use of a scenario driver, such as ISTC, along with the actual NMD hardware and software, high-fidelity hardware-in-the-loop, tactical operators-in-the-loop, and tactical communications links are feasible based on TMDSE experience and would provide realistic testing against the full many-on-many NMD scenarios that cannot be used in live tests.

4.3 Specific Example - Airborne Laser

The Airborne Laser (ABL) is being developed as an antimissile element of TMD architectures. A real-time, operator-in-the-loop ABL simulation has been developed at the Theater Air Command and Control Simulation Facility (TACCSF), Kirtland Air Force Base, New Mexico [Ref. 27]. The simulation is capable of interacting in distributed exercises which provide the ABL System Program Office with a unique environment for testing both operational and technical concepts. There are recommendations for using linked testing to form a robust capability of evaluate overall ABL system performance in a joint theater environment [Ref. 28]. Since ADS can link together portions of the ABL system and TMD architecture, this test capability should be able to examine all functional areas at the engagement, mission, and theater levels.

Distributed tests involving the TACCSF ABL simulation are encouraged, since they are feasible and would provide a means for realistic evaluation of the ABL at the mission and theater levels. In particular, the BM/C3 functional area can be addressed at the theater level using distributed testing.

5.0 Conclusion

5.1 Summary

The findings from the ETE Test support the conclusion that ADS has significant utility for C4ISR DT&E and OT&E. In fact, ADS techniques can potentially be applied to all C4ISR acquisition phases. ADS is an enabling technology for STEP and SBA, and ADS is useful for supporting the iterative spiral development process. There are benefits to the appropriate use of ADS in support of C4ISR testing including its use as a viable technique for performing realistic mission-level evaluations. Constraints and concerns for implementing ADS are more programmatic and cultural than technical.

This report gives general guidelines for implementation of ADS-based testing of C4ISR systems. Detailed requirements for linking specific C4ISR systems using specific architectures were not developed.

The ETE Test results strongly suggest that ADS has excellent potential for improving C4ISR testing and system acquisition. Thus, test planners and program managers should consider the technology as a relevant tool for their program unless an objective assessment suggests otherwise.

5.2 Recommendations

JADS recommends the following in order to increase the utility of ADS to C4ISR programs.

- Require that ADS approaches be addressed in the acquisition strategy and the test and evaluation master plan (TEMP) for new C4ISR acquisition programs.
- Direct all programs to focus on the ability of ADS to overcome any identified test limitations.
- When making an ADS go/no go decision, compare ADS costs and benefits to those of the alternative method(s).
- Develop infrastructure to reduce the costs of linking.
- Use an ADS environment over the life of a program.
- Use JADS-developed ADS methodologies, e.g., test planning, verification and validation, ADS implementation.
- Institute ADS training at formal T&E and acquisition schools.
- Nurture ground-breaking programs, e.g., FI 2010, Joint Strike Fighter.
- Subsidize service ADS pilot projects on C4ISR acquisition programs.
- Use ADS to enhance real-time data analysis and test efficiency.
- Develop inherent linking capability at facilities and ranges.
- Provide on-call WAN access.
- Develop robust standards for interoperability of both DSMs and test ranges and facilities.

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Appendix A - List of Acronyms

ABL	Airborne Laser
ADS	advanced distributed simulation
AFATDS	Advanced Field Artillery Tactical Data System
AFOTEC	Air Force Operational Test and Evaluation Center
AO	attack operations
ARC	Advanced Research Center, Huntsville, Alabama
ASAS	All Source Analysis System
ATACMS	Army Tactical Missile System
ATWS	Advanced Technology Work Station
BM/C3	Battle Management Command, Control, and Communications
BMDO	Ballistic Missile Defense Organization
C2	command and control
C3	command, control, and communications
C3I	command, control, communications, and intelligence
C4I	command, control, communications, computers and intelligence
C4ISR	command, control, communications, computers, intelligence, surveillance and reconnaissance
CAMPS	Compartmented All Source Analysis System (ASAS) Message Processing System
CGS	common ground station
ConOps	concept of operation
CSU	channel service unit
CTEIP	Central Test and Evaluation Investment Program
DD, DT&E/S&TS	Deputy Director, Developmental Test and Evaluation, Strategic and Tactical Systems
DIS	distributed interactive simulation
DMAP	data management and analysis plan
DMSO	Defense Modeling and Simulation Organization, Alexandria, Virginia
DoD	Department of Defense
DoDD	Department of Defense directive
DREN	Defense Research and Engineering Network
DSI	Defense Simulation Internet
DSM	digital system model
DSU	data service unit
DT&E	developmental test and evaluation
ETE	end-to-end
EW	electronic warfare
FBCB2	Force XXI Battle Command Brigade and Below
FDC	fire direction center
FED	federation
FEDEP	federation development and execution process
FI 2010	Foundation Initiative 2010

FOM	federation object model
FoS	family of systems
GBI	ground based interceptor
GBR	ground based radar
HLA	high level architecture
ICD	interface control document
IEEE	Institute of Electrical and Electronics Engineers
ISG	Implementation Study Group
ISTC	integrated system test capability
ITEA	International Test and Evaluation Association
JADS	Joint Advanced Distributed Simulation, Albuquerque, New Mexico
Janus	interactive, computer-based simulation of combat operations
JNTF	Joint National Test Facility, Falcon Air Force Base, Colorado
Joint STARS	Joint Surveillance Target Attack Radar System
JSIMS	Joint Simulation System
JT&E	joint test and evaluation
JTF	joint test force
JTMD AO	Joint Theater Missile Defense Attack Operations
LGSM	light ground station module
LOS	line-of-sight
M&S	modeling and simulation
NMD	National Missile Defense
OPTEMPO	operations tempo
OSD	Office of the Secretary of Defense
OT&E	operational test and evaluation
PDU	protocol data unit
RTI	runtime infrastructure
SAIC	Science Applications International Corporation
SATCOM	satellite communications
SBA	Simulation Based Acquisition
SBIRS	Space Based Infrared System
SCDL	surveillance and control data link
SIE	system integrated exercise
SIPRNET	Secure Internet Protocol Router Network
SISO	Simulation Interoperability Standards Organization
SIT	system integration test
SIW	simulation interoperability workshop
STEP	Simulation, Test, and Evaluation Process
STORM	Simulation, Testing, Operations, Rehearsal Model
STOW	Synthetic Theater of War
T&E	test and evaluation
T-1	digital carrier used to transmit a formatted digital signal at 1.544 megabits per second
TAC	target analysis cell
TACCSF	Theater Air Command and Control Simulation Facility

TAFSM	Tactical Army Fire Support Model
TCAC	Test Control and Analysis Center, Albuquerque, New Mexico
TECOM	Test and Evaluation Command
TEMP	test and evaluation master plan
TENA	Test and Training Enabling Network Architecture
TMD	Theater Missile Defense
TMDSE	Theater Missile Defense System Exerciser
TRAC	U.S. Army Training and Doctrine Command (TRADOC) Analysis Center
TRADOC	U.S. Army Training and Doctrine Command
TSPI	time-space-position information
UAV	unmanned aerial vehicle
UEWR	Upgraded Early Warning Radar
VPG	virtual proving ground
VSTARS	Virtual Surveillance Target Attack Radar System
VV&A	verification, validation and accreditation
WAN	wide area network
WSMR	White Sands Missile Range

Appendix B - Glossary

A

Accreditation. See: distributed simulation accreditation, model/simulation accreditation.

Accuracy. The degree of exactness of a model or simulation relative to an established standard with high accuracy implying low error. [DIS]

Activity. An event that consumes time and resources and whose performance is necessary for a system to move from one event to the next. [DIS]

Advanced Distributed Simulation (ADS). A set of disparate models or simulations operating in a common synthetic environment. The ADS may be composed of three modes of simulation: live, virtual and constructive, where the latter can be seamlessly integrated within a single exercise. See also: live simulation; virtual simulation; constructive simulation. [DIS]

Aggregate. An activity that combines individual entities into a singular entity. **Contrast with:** disaggregate. [DIS]

B

Battlespace. The three-dimensional battlefield. [DIS]

Benchmark. (v) The activity of comparing the results of a model or simulation with an accepted representation of the process being modeled. (n) The accepted representation of the modeled process. [DIS]

Bit. The smallest unit of information in the binary system of notation. [IEEE 1278.1]

Broadcast. A transmission mode in which a single message is sent to all network destinations, i.e., one-to-all. Broadcast is a special case of multicast. **Contrast with:** multicast; unicast. [IEEE 1278.2]

C

Compatible. Two or more simulations are distributed interactive simulation (DIS) compatible if (1) they are DIS compliant, and (2) their models and data that send and interpret protocol data units (PDUs) support the realization of a common operational environment among the systems (coherent in time and space). **Contrast with:** compliant, interoperable. [DIS]

Compliant. A simulation is distributed interactive simulation (DIS) compliant if it can send or receive protocol data units (PDUs) in accordance with Institute of Electrical and Electronics Engineers (IEEE) Standard 1278 and 1278 (working drafts). A specific statement must be made regarding the qualifications of each PDU. **Contrast with:** compatible, interoperable. [DIS]

Conceptual Model. A description of the content and internal representations which are the user's and developer's combined concepts of the exercise. It includes logic and algorithms and explicitly recognizes assumptions and limitations. [DIS]

Constructive Simulation. Models and simulations that involve simulated people operating simulated systems. **See Also:** war games; higher order model (HOM). [DIS]

Continuous Model. (1) A mathematical or computational model whose output variables change in a continuous manner; that is, in changing from one value to another, a variable can take on all intermediate values. For example, a model depicting the rate of air flow over an airplane wing. **Syn:** continuous-variable model. (2) A model of a system that behaves in a continuous manner. **Contrast with:** discrete model. [DIS]

Continuous Simulation. A simulation that uses a continuous model. [DIS]

Continuous-Variable Model. **See:** continuous model. [DIS]

Control Station. (1) A facility which provides the individual responsible for controlling the simulation and the capability to implement simulation control as protocol data units (PDUs) on the distributed interactive simulation (DIS) network.

Syn: simulation - management station. [DIS]

D

Data. Representation of facts, concepts, or instructions in a formalized manner suitable for communication, interpretation or processing by humans or automatic means. [DIS]

Database. A collection of data organized according to a schema to serve one or more applications. [DIS]

Data Certification. The determination that data have been verified and validated. (1) Data producer certification is the determination by the data producer that data have been verified and validated against documented standards of criteria. (2) Data user certification is the determination by the application sponsor or designated agent that data have been verified and validated as appropriate for the specific modeling and simulation (M&S) usage. [DIS]

Data Logger. A device that accepts protocol data units (PDUs) from the network and stores them for later replay in the same time sequence as the PDUs were originally received. **See also:** protocol data unit (PDU). [IEEE 1278.3]

Data Validation. The documented assessment of data by subject area experts and its comparison to known or best-estimate values. (1) Data producer validation is that documented assessment within stated criteria and assumptions. (2) Data user validation is that documented assessment of data as appropriate for use in an intended modeling and simulation (M&S). [DIS]

Data Verification. The use of techniques and procedures to ensure that data meet specified constraints defined by data standards and business rules. (1) Data producer verification is the use of techniques and procedures to ensure that data meet constraints defined by data standards and business rules derived from process and data modeling. (2) Data user verification is the use of techniques and procedures to ensure that data meet user specified constraints defined by data standards and business rules derived from process and data modeling and that data are transformed and formatted properly. [DIS]

Data Verification, Validation, and Certification. The process of verifying the internal consistency and correctness of data, validating that they represent real-world entities appropriate for their intended purpose or an expected range of purposes, and certifying them as having a specified level of quality or as being appropriate for a specified use, type of use, or range of uses. The process has two perspectives: producer and user process. **See:** data validation, data verification, and data certification. [DIS]

Dead Reckoning. **See:** remote entity approximation.

Deaggregate. **See:** disaggregate. [DIS]

Distributed Interactive Simulation (DIS). A synthetic environment within which humans may interact through simulation(s) at multiple sites networked using compliant architecture, protocols, standards, and databases (DoDD 5000.59P)

E

Electronic Battlefield. **See:** synthetic environment. [DIS]

Entity. Any component in a system that requires explicit representation in a model. Entities possess attributes denoting specific properties. **See:** simulation entity. [DIS]

Environment. (1) The texture or detail of the domain, such as cities, farmland, sea states, etc. (2) The external objects, conditions, and processes that influence the behavior of a system (such as terrain relief, weather, day, night, terrain cultural features, etc.) [DIS]

Event. (1) An occurrence that causes a change of state in a simulation. **See also:** conditional event; time-dependent event. (2) The instant in time at which a change in some variable occurs. [DIS]

Event-Driven Simulation. **See:** event-oriented simulation. [DIS]

Event-Oriented Simulation. A simulation in which attention is focused on the occurrence of events and the times at which those events occur; for example, a simulation of a digital circuit that focuses on the time of state transition. **Syn:** event-driven simulation; event-sequenced simulation. [DIS]

Event-Sequenced Simulation. **See:** event-oriented simulation. [DIS]

Exercise. (1) One or more sessions with a common objective and accreditation. (2) The total process of designing, assembling, testing, conducting, evaluating, and reporting on an activity. **See:** simulation exercise. **Syn:** experiment, demonstration. [DIS, IEEE 1278.3]

F

Fidelity. (1) The similarity, both physical and functional, between the simulation and that which it simulates. (2) A measure of the realism of a simulation. (3) The degree to which the representation within a simulation is similar to a real-world object, feature, or condition in a measurable or perceivable manner. **See also:** model/simulation validation. [DIS, IEEE 1278.1]

Field. (1) A series of contiguous bits, treated as an instance of a particular data type, that may be part of a higher level data structure. (2) An external operating area for actual vehicles or live entities. **See:** field instrumentation. [DIS, IEEE 1278.1]

G

Graphical Model. A symbolic model whose properties are expressed in diagrams. For example, a decision tree used to express a complex procedure. **Contrast with:** mathematical model; narrative model; software model; tabular model. [DIS]

Ground Truth. The actual facts of a situation without errors introduced by sensors or human perception and judgment. [DIS]

H

Human-in-the-Loop Model. **See:** interactive model.

Human-Machine Simulation. A simulation carried out by both human participants and computers, typically with the human participants asked to make decisions and a computer performing processing based on those decisions. [DIS]

I

Interactive Model. A model that requires human participation. **Syn:** human-in-the-loop model. [DIS]

Interoperable. Two or more simulations are distributed interactive simulation (DIS) interoperable for a given exercise if they are DIS compliant, DIS compatible, and their performance characteristics support a fair fight to the fidelity required for the exercise. **Contrast with:** compatible, compliant. [DIS]

Interoperability. (1) The ability of a set of simulation entities to interact with an acceptable degree of fidelity. The acceptability of a model is determined by the user for the specific purpose of the exercise, test, or analysis. (2) The ability of a set of distributed interactive simulation applications to interact through the exchange of protocol data units. [DIS]

L

Live Entity. A perceptible object that can appear in the virtual battlespace but is unaware and nonresponsive (either by intent, lack of capability or circumstance) to the actions of virtual entities. **See also:** field instrumentation. **Contrast with:** live instrumented entity. [DIS]

Live Instrumented Entity. A physical entity that is in the real world and can be represented in the distributed interactive simulation (DIS) virtual battlespace which can be manned or unmanned. The live instrumented entity has internal and/or external field instrumentation (FI) devices/systems to record and relay the entity's surroundings, behavior, and/or reaction to events. If the FI provides a two-way link, the events that affect the live instrumented entity can be occurring in the virtual battlespace as well as the real world. **See also:** field instrumentation, live entity. [DIS]

Local Area Network (LAN). A class of data network which provides high data rate interconnection between network nodes in close physical proximity. [IEEE 1278.3]

M

Measure of Performance (MOP). Measure of how the system/individual performs its functions in a given environment (e.g., number of targets detected, reaction time, number of targets nominated, susceptibility of deception, task completion time). It is closely related to inherent parameters (physical and structural) but measures attributes of system behavior. **See also:** measures of effectiveness (MOE). [IEE 1278.3]

Model. (1) An approximation, representation, or idealization of selected aspects of the structure, behavior, operation, or other characteristics of a real-world process, concept, or system. Note: Models may have other models as components. (2) To serve as a model as in (1). (3) To develop or use a model as in (1). (4) A mathematical or otherwise logical representation of a system or a system's behavior over time. [DIS]

Model/Simulation Accreditation. The official certification that a model or simulation is acceptable for use for a specific purpose. **See also:** distributed simulation accreditation.

Contrast with: model/simulation validation, model/simulation verification. [DoDD 5000.59]

Model/Simulation Validation. The process of determining the degree to which a model is an accurate representation of the real world from the perspective of the intended use(s) of the model. **See also:** distributed simulation validation, fidelity. **Contrast with:** model simulation accreditation, model simulation verification. [DoDD 5000.59]

Model/Simulation Verification. The process of determining that a model implementation accurately represents the developer's conceptual description and specifications. **See also:** distributed simulation verification. **Contrast with:** model simulation accreditation, model simulation validation. [DoDD 5000.59]

N

Network Filter. A system to selectively accept or reject data received from the network. [DIS]

Network Node. A specific network address. **See:** node. **Contrast with:** processing node. [DIS]

Node. A general term denoting either a switching element in a network or a host computer attached to a network. **See:** processing node; network node. [IEEE 1278.1, IEEE 1278.2]

O

Operational Environment. A composite of the conditions, circumstances, and influences which affect the employment of military (or other) forces and the decisions of the unit commander or person in charge. [DIS]

P

Platform. A generic term used to describe a level of representation equating to vehicles, aircraft, missiles, ships, fixed sites, etc., in the hierarchy of representation possibilities. Other representation levels include units (made up of platforms) and components or modules (which make up platforms.) [DIS]

Protocol Data Unit (PDU). A distributed interactive simulation (DIS) data message that is passed on a network between simulation applications according to a defined protocol. [IEEE 1278.1]

R

Real Time. In modeling and simulation, simulated time advances at the same rate as actual time; for example, running the simulation for one second results in the model advancing time by one second. **Contrast with:** fast time, slow time. [DIS]

Resolution. (1) The degree to which near equal results values can be discriminated. (2) The measure of the ability to delineate picture detail. [DIS]

S

Scenario. (1) Description of an exercise (initial conditions). It is part of the session database which configures the units and platforms and places them in specific locations with specific missions. (2) An initial set of conditions and time line of significant events imposed on trainees or systems to achieve exercise objectives. **See:** field exercise. [DIS, IEEE 1278.3]

SIMNET (Simulator Networking). The prototype distributed simulation upon which distributed interactive simulation (DIS) was based. [DIS]

Simulate. To represent a system by a model that behaves or operates like the system. **See also:** emulate. [DIS]

Simulated Time. Time as represented within a simulation. **Syn:** virtual time. **See also:** fast time; real time; slow time. [DIS]

Simulation. (1) A model that behaves or operates like a given system when provided a set of controlled inputs. **Syn:** simulation model. **See also:** emulation. (2) The process of developing or using a model as in (1). (3) An implementation of a special kind of model that represents at least some key internal elements of a system and describes how those elements interact over time. [DIS]

Simulation Environment. (1) Consists of the natural physical environment surrounding the simulation entities including land, oceans, atmosphere, near-space, and cultural information. (2) All the conditions, circumstances, and influences surrounding and affecting simulation entities including those stated in (1). [DIS]

Simulation Exercise. An exercise that consists of one or more interacting simulation applications. Simulations participating in the same simulation exercise share a common identifying number called the exercise identifier. These simulations also utilize correlated representations of the synthetic environment in which they operate. **See:** live simulation. [IEEE 1278.1, IEEE 1278.2]

Simulation Fidelity. Refers to the degree of similarity between the simulated situation and the operational situation. [IEEE 1278.3]

Simulation Time. (1) A simulation's internal representation of time. Simulation time may accumulate faster, slower, or at the same pace as real time. (2) The reference time (e.g., universal coordinated time) within a simulation exercise. This time is established ahead of time by the simulation management function and is common to all participants in a particular exercise. [DIS, IEEE 1278.1]

Simulator. (1) A device, computer program, or system that performs simulation. (2) For training, a device which duplicates the essential features of a task situation and provides for direct practice. (3) For distributed interactive simulation (DIS), a physical model or simulation of a weapons system, set of weapon systems, or piece of equipment which represents some major aspects of the equipment's operation. [DIS]

Site. (1) An actual physical location at a specific geographic area, e.g., the Fort Knox Close Combat Test Bed (CCTB). (2) A node on the network used for distributed simulation such as the Defense Simulation Internet (DSI) long haul network. (3) A level of configuration authority within a distributed interactive simulation (DIS) exercise. [DIS]

V

Validation. See: data validation, distributed simulation validation, face validation, model/simulation validation. [DIS]

Verification. See: data verification, distributed simulation verification, model/simulation verification

Verification and Validation (V&V) Proponent. The agency responsible for ensuring V&V is performed on a specific model or simulation. [DIS]

Vignette. A self-contained portion of a scenario. [DIS]

Virtual Battlespace. The illusion resulting from simulating the actual battlespace. [DIS]

W

War Game. A simulation game in which participants seek to achieve a specified military objective given pre-established resources and constraints; for example, a simulation in which participants make battlefield decisions and a computer determines the results of those decisions. **See also:** management game. **Syn:** constructive simulation; higher order model (HOM). [DIS]

Wide Area Network (WAN). A communications network of devices which are separated by substantial geographical distance. **Syn:** long haul network. [IEEE 1278.3]

Appendix C - ADS Test Implementation Checklist

This appendix outlines useful procedures in implementing ADS-based testing based on steps given in the HLA Federation Development and Execution Process (FEDEP) Model⁸. The more detailed version of this checklist is available from the JADS JTF as the "Special Report on Advanced Distributed Simulation-Inclusive Test and Evaluation Methodologies."⁹

STEP 1: Define Distributed Test Objectives

Activity 1.1: Identify Needs

- Activity Purpose: develop clear understanding of the problem to be addressed by the distributed test.
- Activity Inputs: program objectives, test requirements, and information on resources available to support a distributed test.
- Activity Output: needs statement.

Activity 1.2: Develop Objectives

- Activity Purpose: refine the needs statement into a more detailed set of specific objectives for the distributed test.
- Activity Inputs: needs statement from previous activity.
- Activity Outputs: statement of the test objectives and initial planning documents.

STEP 2: Develop Conceptual Model

Activity 2.1: Develop Scenario

- Activity Purpose: develop a functional specification of the test scenario.
- Activity Inputs: operational context constraints specified in the test objectives statement.
- Activity Output: test scenario description.

Activity 2.2: Perform Conceptual Analysis

- Activity Purpose: produce a conceptual model of the ADS environment.
- Activity Inputs: test scenario description from previous activity, test objectives statement, and any doctrine and tactics appropriate for the scenario.
- Activity Output: conceptual model, which is a description of the players, their actions, and any interactions among players that need to be included in the distributed test in order to achieve all test objectives.

Activity 2.3: Develop Distributed Test Requirements

- Activity Purpose: define top-level test requirements.
- Activity Input: conceptual model from previous activity.
- Activity Output: (1) requirements that are based on the distributed test objectives, are directly testable, and provide the implementation level guidance needed to design and

⁸ "High Level Architecture Federation Development and Execution Process (FEDEP) Model, Version 1.3," 9 December 1998 available from the Defense Modeling and Simulation Organization (DMSO) HLA Web site located at <http://hla.dmsi.mil/>.

⁹ To be available at <http://www.jads.abq.com> on or about 30 September 1999. (After 1 March 2000 refer requests to HQ AFOTEC/HO, 8500 Gibson Blvd. SE, Kirtland Air Force Base, New Mexico 87117-5558 or the SAIC Technical Library, 2001 North Beauregard St. Suite 800, Alexandria, Virginia 22311.)

develop the distributed test, and (2) requirements-based criteria for evaluating test results. Major top-level requirements that should be addressed include the following:

- Fidelity requirements for all players represented in the test scenarios.
- Interaction requirements specifying information types that must be exchanged among players to permit interactions.
- Latency requirements for the maximum acceptable latency for each pair of interacting players.
- Data reliability requirements specifying the maximum acceptable level of ADS-induced errors, such as dropout rate and out-of-order messages.
- Data analysis requirements including a data management and analysis plan (DMAP) detailing the analysis approach for each test objective.

STEP 3: Design and Develop Distributed Test

Activity 3.1: Design ADS Architecture

- Activity Purpose: establish the player representations in the distributed test and develop a coordinated plan to guide its development, test, and execution.
- Activity Inputs: test requirements, test scenario, conceptual model, and the initial planning documents.
- Activity Outputs: identification of specific player representations selected and a detailed test plan. The steps for this activity are as follows.
 - Select specific player representations.
 - Develop additional requirements needed for architecture design including:
 - Data requirements including data rates, time-space-position information (TSPI) accuracy and smoothness, data time-stamp accuracy, and classification of the data and any security handling procedures.
 - Data synchronization requirements.
 - Real-time data processing requirements.
 - Terrain database requirements.
 - Data collection/instrumentation requirements.
 - Post-test data management requirements.
 - Interface requirements to include simulation interfaces, special-purpose interfaces, and interfaces to the runtime infrastructure (RTI) for HLA implementation.
 - Test control and monitoring requirements.
 - Determine if modifications to the selected player representations are needed, such as:
 - Simulation modifications needed to utilize external inputs.
 - Simulation modifications needed to generate the required outputs.
 - Data processing modifications needed to meet TSPI accuracy, smoothness, and latency requirements.
 - Facility modifications needed for a replay capability that can be used during integration testing.
 - Determine network design requirements including the following:
 - Data protocols to be used.
 - Decide if HLA will be implemented.
 - Determine if data from each node will be broadcast, multicast, or unicast (transmitted point-to-point).

- Determine if data are to be transmitted using best effort or reliable procedures.
- Determine network security approach to be implemented.
- Determine the wide area network (WAN) bandwidth requirement.
- Prepare a detailed plan including a detailed DMAP, verification, validation and accreditation (VV&A) plan, and an interface control document (ICD).

Activity 3.2: Develop ADS Architecture

- Activity Purpose: develop the federation object model (FOM) if HLA is to be implemented, modify the simulations/range facilities, if necessary, and prepare the distributed architecture for integration and test.
- Activity Inputs: detailed test plan and specific player representations identified in the previous activity.
- Activity Outputs: FOM and federation execution data (FED) file if HLA is to be implemented and the modified player representations. The ADS architecture is developed during this activity using the following steps:
 - Conduct surveys of each site to be linked by the network.
 - Select and procure the WAN to be used to link the nodes/facilities.
 - Select and procure the network hardware, including routers, channel service units (CSUs)/data service units (DSUs), multiplexers, encryptors, etc.
 - Select and procure test control hardware and software.
 - Select and procure and/or develop network analysis/monitoring tools.
 - Develop detailed procedures for secure/encrypted operations and obtain approval for their use from the designated approval authority.

STEP 4: Integrate and Test Architecture

Activity 4.1: Plan Execution

- Activity Purpose: define and develop the full set of information required to support the distributed test execution.
- Activity Inputs: FOM and FED file if HLA is to be implemented and the detailed test plan.
- Activity Outputs: refined and detailed integration test plan, VV&A plan, and test procedures. The integration test plan should address the following:
 - Procedures for verifying any simulation/range facility modification in a systematic stand-alone fashion.
 - Procedures for initially testing each WAN link separately.
 - Procedures for testing each simulation-to-simulation connection with all network nodes connected.
 - Procedures for testing the voice communications with all equipment and personnel as in the actual test.

Activity 4.2: Integrate and Test ADS Architecture

- Activity Purpose: bring all the distributed test participants into a unifying operating environment and verify that they can all interoperate to the degree required to achieve the test objectives.
- Activity Inputs: detailed test plan, VV&A plan, and test procedures.

- Activity Outputs: refined test procedures, VV&A results, and an ADS architecture which has been thoroughly tested and is ready for test execution. Key steps during this activity include the following:
 - Implement the simulation/range facility modifications needed for linking, as determined during Activity 3.1.
 - Build/procure the necessary interfaces for linking in accordance with the requirements developed during Activity 3.1.
 - Install the network hardware and software.
 - Perform compliance testing as specified in the VV&A plan.
 - Perform integration testing as specified in the integration test plan.
 - Perform risk reduction missions.
 - Perform validation as specified in the VV&A plan.

STEP 5: Execute Distributed Test and Analyze Results

Activity 5.1: Execute Distributed Test

- Activity Purpose: exercise all distributed test participants as an integrated whole to generate required outputs and achieve the stated test objectives.
- Activity Inputs: refined test procedures and tested ADS architecture from integration testing.
- Activity Output: raw test results. The following considerations apply during execution:
 - Pre- and post-test briefings are essential.
 - Centralized test control/management and execution monitoring must be maintained following detailed test control procedures and checklists.
 - Data collected during execution are used to support both quick-look and detailed post-test analyses.
 - Strict attention must be given to maintaining the security posture of the ADS architecture during execution.
 - Conduct an after-action review immediately after the test in order to gather important information from each facility, to formulate a course of action for correcting any problems, and to prepare for the next period of testing.

Activity 5.2: Process Output

- Activity Purpose: post-process (as necessary) the output collected during test execution.
- Activity Input: raw test results from test execution.
- Activity Output: derived test results.

Activity 5.3: Prepare Results

- Activity Purpose: (1) evaluate the data analysis results in order to determine if all test objectives have been met and (2) identify legacy products and make them available to other programs.
- Activity Input: derived test results along with the test evaluation criteria from Activity 2.3.
- Activity Output: documented test results and legacy products.

Appendix D - JADS ETE Test Bibliography

NOTE: These papers and reports can be downloaded from the JADS Web site:
<http://www.jads.abq.com>.¹⁰

Floto, R., "A Real-Time Stochastic MTI Radar Simulation for DIS Application," Proceedings of the American Institute of Aeronautics and Astronautics Flight Simulation Technology Conference, July 1996.

Gonzalez, D. and J. Black, "Collection and Analysis of Quality Data in a Distributed Simulation Test Environment," Proceedings of the International Test and Evaluation Association Modeling and Simulation Workshop, Las Cruces, New Mexico, 9-12 December 1996.

Gonzalez, D. and J. Black, "The JADS Analysis Toolbox (A Toolbox for Analysis of Distributed Simulations)," Proceedings of the Simulation Interoperability Standards Organization Spring 1999 Simulation Interoperability Workshop, Orlando, Florida, 14-19 March 1999.

Houser, R., "The Future of Digital Terrain in Distributed Simulations," Proceedings of the International Test and Evaluation Association Modeling and Simulation Workshop, Las Cruces, New Mexico, 7-10 December 1998.

Hovey, P., End-to-End Interim Report Phase 2, JADS JT&E-TR-99-005, Joint Advanced Distributed Simulation Joint Test and Evaluation, Albuquerque, New Mexico, February 1999.

Marchand, G., "A Plug and Play Joint Test Environment for Future Operational Testing," Proceedings of the International Test and Evaluation Association International Symposium, Orlando, Florida, 16-19 September 1997.

Marchand, G., "A V&V Strategy for Advanced Distributed Simulation in Support of a Test," Proceedings of the International Test and Evaluation Association Modeling and Simulation Workshop, Las Cruces, New Mexico, 9-12 December 1996.

Marchand, G., "ETE Update - ADS Testing of C4ISR Systems," Proceedings of the International Test and Evaluation Association Modeling and Simulation Workshop, Las Cruces, New Mexico, 7-10 December 1998.

Marchand, G., "VSTARS - A STEP Success Story," Proceedings of the International Test and Evaluation Association Modeling and Simulation Workshop, Las Cruces, New Mexico, 7-10 December 1998.

¹⁰ After 1 March 2000 refer requests to HQ AFOTEC/HO, 8500 Gibson Blvd. SE, Kirtland Air Force Base, New Mexico 87117-5558 (phone: 505-846-2579) or the SAIC Technical Library, 2001 North Beauregard St. Suite 800, Alexandria, Virginia 22311 (phone: 703-578-8222).

Marchand, G. and T. Schmidt, "The Development of a Real-Time Stochastic Radar Simulation (VSTARS)," Proceedings of the International Test and Evaluation Association Modeling and Simulation Workshop, Las Cruces, New Mexico, 9-12 December 1996.

McCall, J. M. and G. J. Marchand, End-to-End Interim Report, Phase 1, JADS JT&E-TR-98-004, Joint Advanced Distributed Simulation Joint Test and Evaluation, Albuquerque, New Mexico, August 1998.

Reeves, J., "Testing and Training in a Command, Control, Communications, and Intelligence (C3I) Framework," Proceedings of the International Test and Evaluation Association Modeling and Simulation Workshop, Las Cruces, New Mexico, 7-10 December 1998.

Schmidt, T. and G. Marchand, "Modification of the Entity State PDU for Use in the End-to-End Test," Proceedings of the International Test and Evaluation Association Modeling and Simulation Workshop, Las Cruces, New Mexico, 9-12 December 1996.

Smith, S., "Analysis Tools and Procedures for Distributed Networks," Proceedings of the International Test and Evaluation Association Modeling and Simulation Workshop, Las Cruces, New Mexico, 7-10 December 1998.

JADS Test Control and Analysis Background Papers

- "ADS Data Loggers"

- "Advanced Distributed Simulation (ADS) Viewers"

- "Communications Line Procurement"

- "The JADS JTF Wide Area Network (WAN)"

- "JADS Voice Networks"

- "Network Analysis Tools"

- "The Selection of a Secure Data Device for the JADS JTF Communications Network"

- "TCAC Time Synchronization"

Appendix E - ADS-Related Web Sites

Air Force Agency for Modeling and Simulation (AFAMS)

<http://www.afams.af.mil/>

Air Force Modeling and Simulation Resource Repository (AFMSRR)

<http://afmsrr.afams.af.mil/>

Defense Modeling and Simulation Office (DMSO)

<http://www.dmsso.mil/>

Defense Modeling, Simulation and Tactical Technology Information Analysis Center (DMSTTIAC)

<http://dmsttiac.hq.iitri.com/>

Distributed Simulation Technology, Inc. (DiSTi), HLA training

<http://www.simulation.com/>

Electronic Proving Ground (EPG)

<http://www.epg.army.mil/epg/>

Extended Air Defense Simulation (EADSIM)

<http://www.smdc.army.mil/eadsim.html>

Extended Air Defense Testbed (EADTB)

<http://www.smdc.army.mil/eadtba~2.html>

High Level Architecture (HLA)

<http://hla.dmsso.mil/>

Joint Accreditation Support Activity (JASA)

<http://www.nawcwpns.navy.mil/~jasa/>

Joint Advanced Distributed Simulation (JADS)

<http://www.jads.abq.com/>

Joint Electronic Combat Test Using Simulation (JECSIM)

<http://www.nawcwpns.navy.mil/~jecsim/>

Joint Modeling and Simulation System (JMASS)

<http://www.jmass.wpafb.af.mil/>

Joint National Test Facility (JNTF)

<http://www.jntf.osd.mil/>

Joint Simulation System (JSIMS)
<http://www.jsims.mil/>

MÄK Technologies, Inc., HLA software
<http://www.mak.com/>

National Simulation Center (NSC)
<http://leav-www.army.mil/nsc/>

Naval Air Warfare Center Weapon Division, modeling and simulation/interoperability
<http://sim.mugu.navy.mil/>

Navy Test and Evaluation Modeling and Simulation (TEMS)
<http://www.nawcad.navy.mil/tems/>

Navy Test and Evaluation Repository for Models and Simulations (NTERMS)
<http://nterms.mugu.navy.mil/>

NPSNET Research Group, Naval Postgraduate School
<http://www-npsnet.cs.nps.navy.mil/npsnet/>

OriginalSim, Inc., HLA software development
<http://www.originalsim.com/>

Simulation Interoperability Standards Organization (SISO)
<http://siso.sc.ist.ucf.edu/>

Simulation Interoperability Workshop (SIW)
<http://siso.sc.ist.ucf.edu/siw/>

Space and Missile Defense Battle Lab (SMDBL), U.S. Army Space and Missile Defense Command (USASMDC)
<http://www.smdc.army.mil/SMDBL.HTML>

Synthetic Scene Generation Model (SSGM)
<http://vader.nrl.navy.mil/>

Theater Air Command and Control Simulation Facility (TACCSF)
<http://www.taccsf.kirtland.af.mil/>

Virtual Proving Ground (VPG)
<http://vpg.tecom.army.mil/>